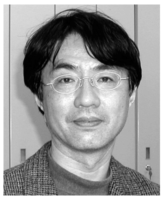

Cooling effect of urban green against urban heat island effect

- PIV observation of the airflow from an urban green space

Hiroshi Miyazaki [1]

[1] *Faculty of Environmental Urban Engineering, Kansai University, 3-3-35 Yamate, Suita, Osaka, 5648680 Japan, h_miyazk@kansai-u.ac.jp*

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1. Introduction

Urban greens, which can supply cool air into the urban, are expected a mitigating role against urban heat island effect (UHI). This is one of researches to clarify the characteristics of cold air flow from green spaces in urban. A lot of researches, which try to elucidate cool airflow from urban green space and cooling effect, have been performed.

Most these researches use sensitive wind gauges and thermometer. Sensitive wind gauges like ultrasonic anemometers were installed in order to clarify the air flow speeds and directions. And thermometers were used to evaluate the cool air accumulation in green parks and the cooling effect in the urban side. There is one problem to observe air flows. Researchers should make a decision according to the height of wind gauges. One simple way to find the answer may be a visualization of the air draft out of the green spaces. For this purpose, I used the Particle image velocimetry (PIV) method to observe thickness, height, velocity, frequency and duration of cool draft out of the green spaces. This study was one of trial to apply this alternative observation method for this kind of researches.

2. Methods and Results

.2-1 Outline of the observation

My research consisted of the following three observations

(1) Air temperature observation from ground level to 3 meters high

(2) Observation of surface temperatures in the green space with thermography camera.

(3) Particle image velocimetry (PIV) observation

The subject green space located in residential area was in Suita City, Osaka. The measurement area was cover with tall trees (8 meters high approx.). Figure 1 shows the subject area (Latitude: 34.822708N, Longitude: 135.517333W, Elevation approx. 100 meters above sea level). The ground surface inclined slightly to the north (Figure 2 shows the section image of the site). I install two measurement points; one measurement point (A) was at the foot of the slope, and the other point (B) was at the top of the slope.

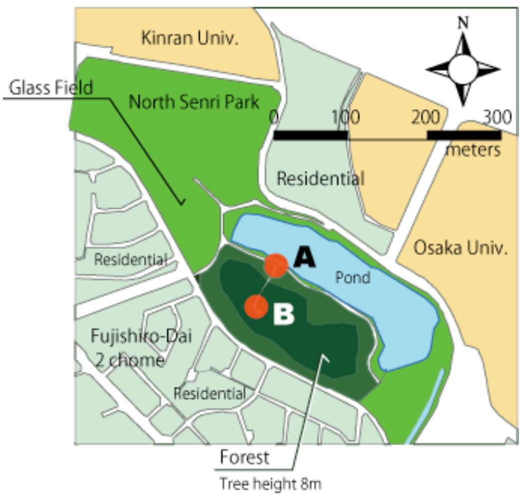


Figure 1: Subject area

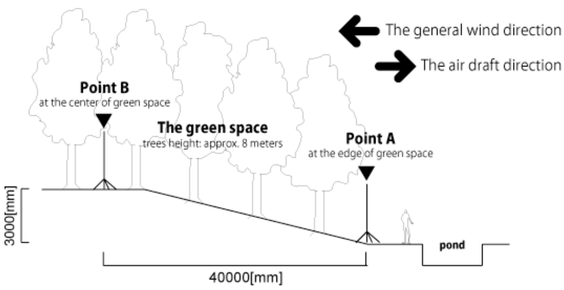


Figure 2: Section image

2-2 Measurement date and term

Previous studies have defined the cool draft frequently appears in nighttime (after sunset and before sunrise) in summer. Following these previous studies, my research started from midnight on 22 September, 2014, and finished early in the morning on the next day. I carried out several observations conventionally in the nighttime, when cool draft air was easy to be generated. The several sets of the measurement started from 23:00 on 22nd September, 2014, and ended 5:00 on the next day. Table 1 shows the measurement items, times and places.

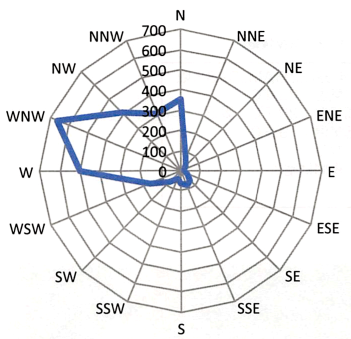
. Table 1: Weather conditions

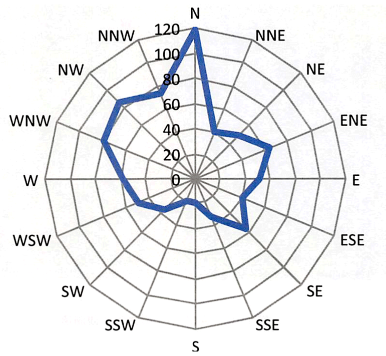
Osaka Meteorological Station
Latitude: 34.681895N, Longitude: 135.519799E
date : 22 September, 2014
daily mean air temperature : 23.4 degree centigrade
daily maximum air temperature : 29.7 degree centigrade
daily minimum air temperature : 19.9 degree centigrade
percipitation : 0.0 mm
weather : clear

2-3 The general winds and weather conditions

In order to distinguish the cool draft air from other kind of winds, the observation of the general winds is important. In order to measure the general wind at the site, I used the following two wind data. One was a self-measured data, which measured wind speeds and directions with a two-dimensional ultrasonic anemometer. The height of this anemometer was 2.5 meters above the ground level. The anemometer set out of the green space. One other wind information was hourly measured data at a municipal meteorological station ("Suita North Fire Station" Latitude: 34.811715N, Longitude:135.516617W, measurement height: 14 meters high) locates 1.2 kilo-meters south from the measurement point.

The weather condition at the day was partly cloudy. The average wind velocity among the measurement term was 0.4 [m/s]. The highest wind velocity was 0.8 [m/s], which recorded at 2:00. It can be said that night was in a calm wind condition. In this study, according to the position of the forest in the park and open spaces, I estimate the wind direction of the cool draft air at the measurement point was to the north. As figure 3 (1) shows, the anemometer at the measurement site shown that the general winds were the side winds at the beginning of the measurement, and were the head winds at the latter part of measurement term. Figure 3 (2) shows the wind rose at the nearest municipal meteorological station.





. Figure 3: Wind rose at the site and municipal meteorological station

2-4 Air temperature observation

Cool air mass, which is generated in the green space, may accumulate on the forest floor. After cool air accumulate to some extent, this air mass may flow out as "cool draft". One of the aims of this air temperature observation was to clarify this process of cool air accumulations. Another aim of this observation was to compare and evaluate the air flows in temperature.

I stood two sets of 3 meters long pole at the center of the green space (Point B in figure 1) and at the edge of the green space (A) vertically on the ground. Each pole equipped 10 thermocouples from the ground level to 3 meters high. With this equipment, I could measure vertical temperature profile. This measurement started at 21:00 and finished 5:00. Time interval was one second. At the point B, this equipment may clarify the process of cool air accumulations. And the difference in temperature at A and B will judge air flows cool for the outside of green space or not. Figure 4 shows the level of thermocouples.

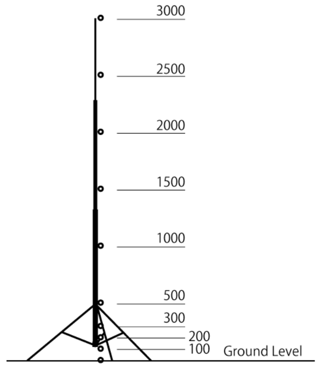
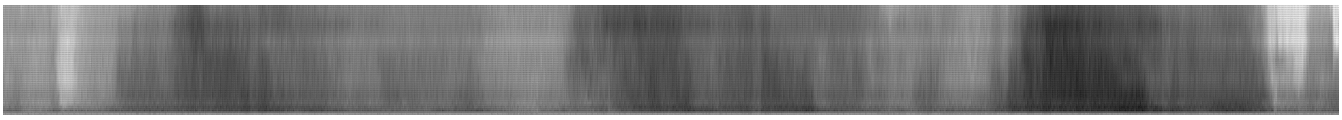
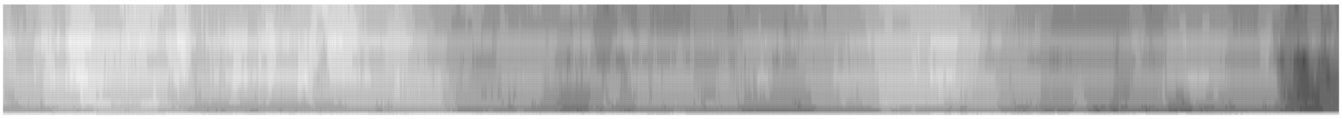


Figure 4: Air temperature measurement equipment

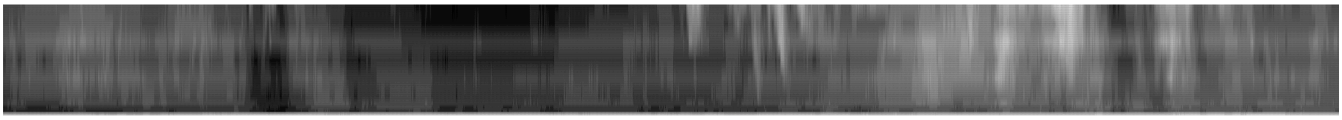
.Figure 5 shows the result. The horizontal axis is the time axis (for example, graph a, 23:00 - 24:00). The vertical axis represents height (ground levet to 3 meters high). Color gradation represents air temperature (light: warm/ dark: cool).



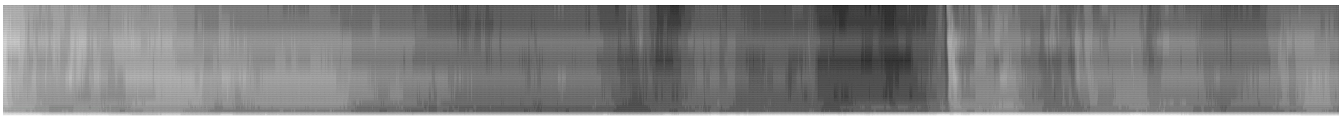
(a) 23:00-24:00 Point A



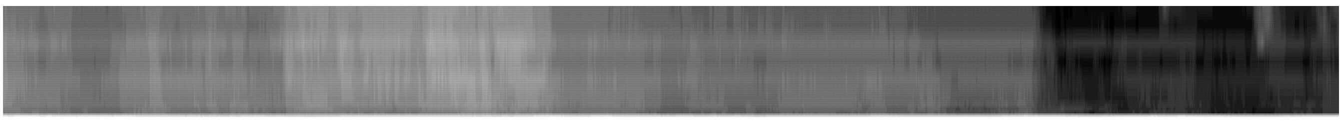
(b) 23:00-24:00 Point B



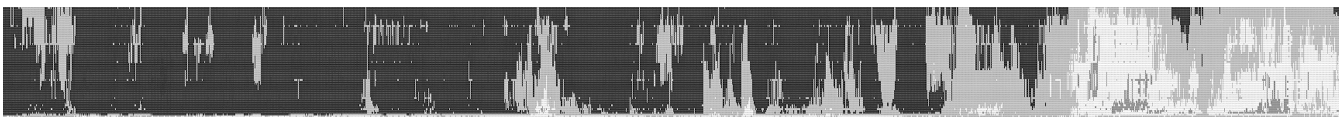
(c) 24:00-1:00 Point B



(d) 2:00-3:00 Point B



(e) 3:00-4:00 Point B



(f) 23:00 Temperature difference (Point B – Point A)

Figure 5: Vertical profile of air temperature

In these figures, dark triangles or dark trapezoids are recognized. These may accumulations of cool air on the forest floor. In general cycle of air temperature change was 3 - 4 times per an hour.

Figures 6 (a) and (b) show the vertical profile of mean air temperature at each level. Lines in this figure consist of two groups. One is the mean air temperature in the inflow term and the other is the mean air temperature in the outflow term. The distinction between inflow and outflow had been done by using PIV observation at the point A. Value of each air temperature is average among approx. 10 minutes observation.

Left two lines in figures 6 (a) and (b) are the air temperature at the edge of the green space (Point A). Right two lines (warmer) are the air temperature, which observed inside of the green space (B). As the figures 6 show, the mean air temperatures at the center of green space were always warmer than the mean air temperature at the edge.

Air temperatures in surrounding residential area were 19.1 degree centigrade at 23:00 (1.3 degree centigrade warmer than hottest air temperature in the green space at the height 1.5 meters), and 17.0 degree centigrade at 4:00 (0.9 degree centigrade warmer).

Figure 6 (b) shows the air flow from outside of the green space was cooler than inside of the green space. Considering the topography around the point A in figure 1, this may be caused that the bottom of sunken filled with cool air at 4:00.

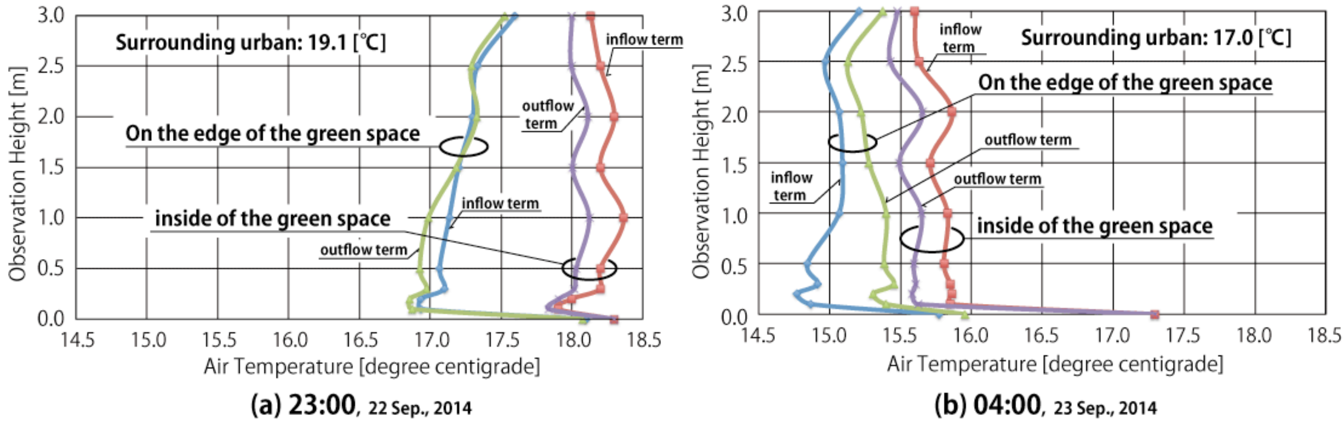


Figure 6: Vertical profile of air temperature

2-5 Surface temperature in the green space

In order to define what surface generates cool air in green spaces, I observed surface temperatures with thermographic camera (Infrared camera, E-6, FLIR System). The observation has done twice; 23:00 and 4:00. Figure 7 (1), (2) shows infrared imageries with this observation. Table 2 shows the result of these observations and average air temperature at 1.5 meters height. Each of temperatures in table 2 is an average of three times measurements. At 23:00, all surface temperatures in green space were higher than air temperature. At 4:00, all surface temperatures in green space were lower than air temperature.

From the observation of air temperature at 23:00 (2-4), the difference in air temperature between inflow and outflow was small at the edge of green space (Figure 6 (a)).

I identified cool draft out of the green space. In other words, cool draft could not be observed at 23:00.

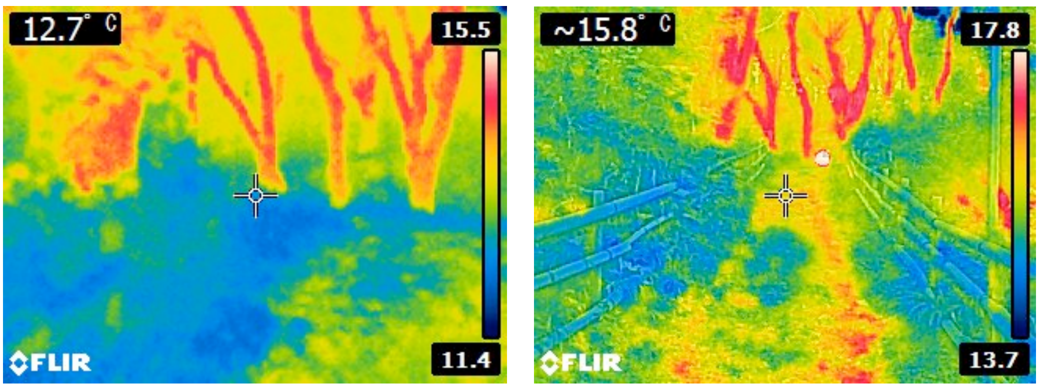


Figure 7: Infrared imageries (example)

Table 2: Surface temperature (Average)

		23:00		4:00	
		Point A	Point B	Point A	Point B
Surface temp. [°C]	Leaf	19.9	19.4	13.9	11.0
	Tree-trunk	21.2	20.0	15.4	12.3
	Ground	20.2	18.6	13.9	11.5
Air Temp. [°C]		17.2	18.0	15.3	15.5

2-6 Particle image velocimetry (PIV) observation

In this observation, in order to visualize an air flows, small particles are mixed in the target air flow as a marker. Green straight laser light illuminates the particles in the air flow and surfaces the section of the air flow. Using high speed consecutive photographs, you can estimate the air flow speed because PIV can measure a transfer distance of a particle or part of a current in a certain interval time.

As a particle, I used was a fine smoke, which was made from mixture of a glycol-based solvent and water. To produce this smoke, I have to heat the mixture liquid to 200 degrees centigrade. In order to cool down the temperature, I catch the smoke in a large plastic bag. Then I released the smoke into the air flow continuously to observe the air draft for a certain long term.

The purpose of my PIV observation was to identify the scale of the air draft from a green space. Here, I tried to identify the depth of airflow, duration time and the speed of draft.

(a) Draft speed

To record the observation and to estimate the draft speed, I take high speed consecutive photographs. Figure 8 is a example of this observation. As the result of several observations, the average speed of air draft was 0.3 meters per second.

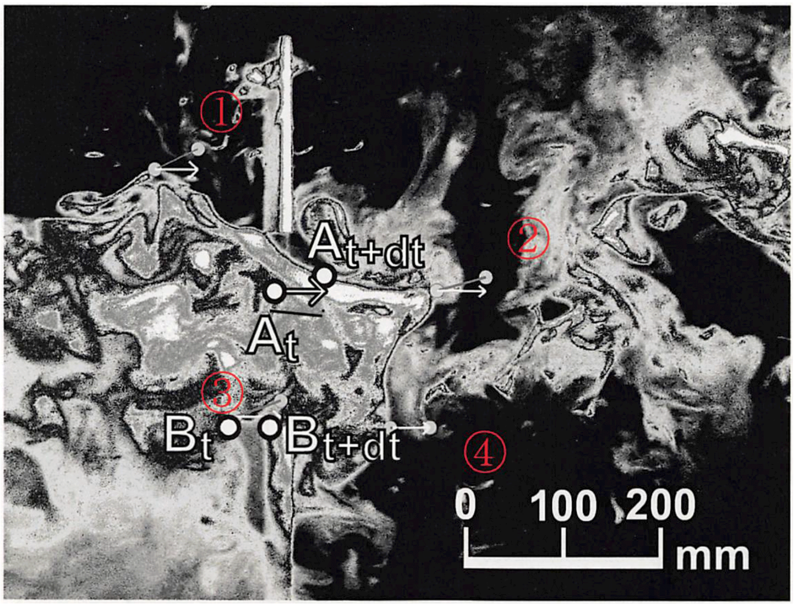


Figure 8: PIV image of outflow draft (detail)

(b) Duration of air draft

In order to measure the duration, I count the time of the drafts. In this observation, the drafts were divided in three categories; (1) outflow, (2) stagnate and (3) inflow. The observation had done at the point A two times; (a) 23:30-23:40 and (b) 4:20-4:30.

Replacements of draft directions were carried out instantly. That is draft speeds and directions chenged rapidly or quickly. Figures 9 show the result of the observation. The ratio of outflow in the total duration time was more than half; 50 % in the term (a), 54 % in the term (b). The time ratio of inflow was around 40 %; 37 % in the term (a), 39 % in the term (b).

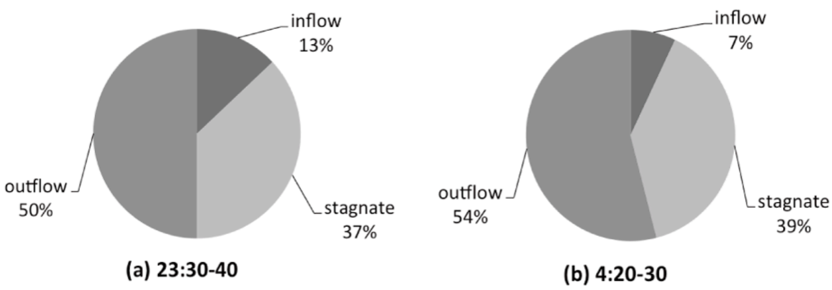


Figure 9: Duration time of each draft directions

(c) Estimated thickness of air draft

Because it was impossible to mix the tracer smoke from the ground level to 3 meters height, here I estimated the thickness of air draft using parameters from the result of the observation. I assume the difference of air density caused by the difference of air temperature may be a driving force of the air draft. The results of the observation (air temperatures and draft velocity) provide the thickness of air draft, if the following equation could express the phenomenon.

$$\frac{1}{2}\rho v^2 = \Delta\rho g h$$

Here, g: gravity acceleration (9.80 m/s^2), ρ: air density (1.20 kg/m^3). ∆ρ: difference of density, which calculated with air temp. in the green space (=18.1∘C) and air temp. in surrounding urban (=19.1∘C). From Eq. 1, the thickness was estimated approx. 1.3 meters.

Conclusion

From my observation, the following knowledge could be acquired.

- From the result of vertical air temperature measurements, accumulations of cool air on the forest floor were recognized. In general, cycles of air temperature change were 3 - 4 times per an hour.
- Air temperatures in the green space were higher than the air temperature at the edge of greens.
- From the result of PIV observations, the velocity of outflow draft from a green space was estimated approx. 0.3 [m/s]
- The ratio of outflow in the total duration time was more than half; 50 %. The time ratio of inflow was around 40 %.
- Cool draft from the green space could be recognized in the head wind conditions.
- The estimated thickness of the draft was estimated about 1.3 meters.

All the results came from only single observation. The results should be conformed with many researches. However, this study identified and gave many information about how the green draft should be observed.

References

[1] Maruta, Y. (1972) : Influence of Green Coverage to Urban Environment, Urban Planning, (69・70), 49-77

[2] Honjou, A. et al. (1998): Micrometeorological Measurement of Urban Vegetation and its Surrounding Area., The Society of Agricultural Meteorology of Japan, 54(4), 323-328, 1998

[3] Takabeyashi, H. and Moriyama, M. (2002): FILLING PROCESS IN A VALLEY AND OUTFLOW PROCESS INTO A BUILT-UP AREA OF COLD AIR DRAINAGE ON SUMMER NIGHT, Architectural Institute of Japan, Journal of Architecture and Planning, (558), 57-61

[4] Takabeyashi, H. and Moriyama, M. (2008): Analysis of cold air drainage from the park in urban area by observations, Journal of Heat Island Institute International Vol.3, 34-39

[5] Narita, K. et al. (2004): Cool-island and Cold Air-seeping Phenomena in an Urban Park, Shinjuku Gyoen, Tokyo, The Association of Japanese Geographers, 77(6), 403-420